CHAPTER

9 Slurry Displacement Piles

Introduction

A slurry displacement pile is a Cast-In-Drilled-Hole (CIDH) pile whose method of construction differs from the usual CIDH pile in that a drilling fluid is introduced into the excavation concurrently with the drilling operation. The drilling fluid, also referred to as slurry or drilling slurry, is used to prevent cave-in of unstable ground formations and intrusion of groundwater into the drilled hole. The drilling slurry remains in the drilled hole until it is displaced by concrete, which is placed under the drilling slurry through a rigid delivery tube.

Because the slurry displacement method is a specific construction method for the construction of CIDH piles, the reader is advised to review Chapter 6 of this manual. Chapter 6 contains information about inspection duties and responsibilities of the Engineer for construction of CIDH piles. This chapter contains modifications of inspection duties and responsibilities of the Engineer as necessary for the construction of CIDH piles using the slurry displacement method.

History

The use of drilling slurry is commonly associated with methods used by the oil well drilling industry over the last 100 years, which naturally provided much of the technical and practical knowledge concerning their use in drilled foundation applications. Use of the slurry displacement method for constructing drilled shafts began in Texas in the years following World War II. This early method involved the use of soil-based drilling slurries to advance the drilled hole, after which a casing was used to stabilize the drilled hole for shaft construction. In the 1960's, processed clay mineral slurry was introduced as a means of eliminating the need for casing to stabilize the drilled hole. However, the properties of the mineral drilling slurries were not controlled. Initial information on the properties of mineral drilling slurries was obtained from the Reese and Touma Research Report, which was a cooperative research program conducted in 1972 by the University of Texas at Austin and the Texas Highway Department. Due to the numerous failures that occurred, by the mid-1970's, more attention was paid to the physical properties of mineral drilling slurries and appropriate methods of preparing and recirculating drilling slurries.

Because processed clay mineral slurries are considered to be environmentally hazardous and are difficult to dispose of, in the 1980's, the drilled shaft industry began a trend towards the use of polymer drilling slurries. These drilling slurries are less hazardous to the environment and are easier to dispose of.

There are still many unknowns about the use of drilling slurries, among them the effect of the drilling slurry on the ability of a pile shaft to develop skin friction. Research done to date has given conflicting results, most of which indicate that pile capacities may be less than that of CIDH piles constructed without the use of drilling slurry. However, the design method used by Caltrans for determining the pile capacity adequately accounts for the potential loss of pile capacity when drilling slurry is used. Research funded in part by the Federal Highway Administration (FHWA) is ongoing at the University of Houston. Caltrans has also conducted research on several contracts in recent years, which has lead to the development of revised contract specifications for use of the slurry displacement method of CIDH pile construction.

Caltrans first used the slurry displacement method on a construction contract in 1984 and has used this method sporadically since then. However, a change in Caltrans seismic design philosophy has resulted in the use of more and larger CIDH piles. Because of this, ground conditions have become less of a factor in the pile type selection process. Other factors such as lower construction costs and construction in an urban environment with restricted access and noise limitations have also led towards the expanded use of CIDH piles. Because of these factors, in 1994 Caltrans started inserting the slurry displacement method specifications into all contracts with CIDH piles.

Slurry Displacement Method

The slurry displacement method of construction is similar to that of ordinary CIDH pile construction until groundwater or caving materials are encountered. When groundwater or caving materials are encountered during the drilling operation, the Contractor must decide whether to use casing to stabilize the drilled hole, dewater the drilled hole, or drill the hole and place concrete under wet conditions using the slurry displacement method. In some cases, the site conditions are known to be wet or unstable. These conditions may be shown on the Log of Test Borings or in the Foundation Report. Sometimes experience on adjacent projects may also give an indication of the site conditions.

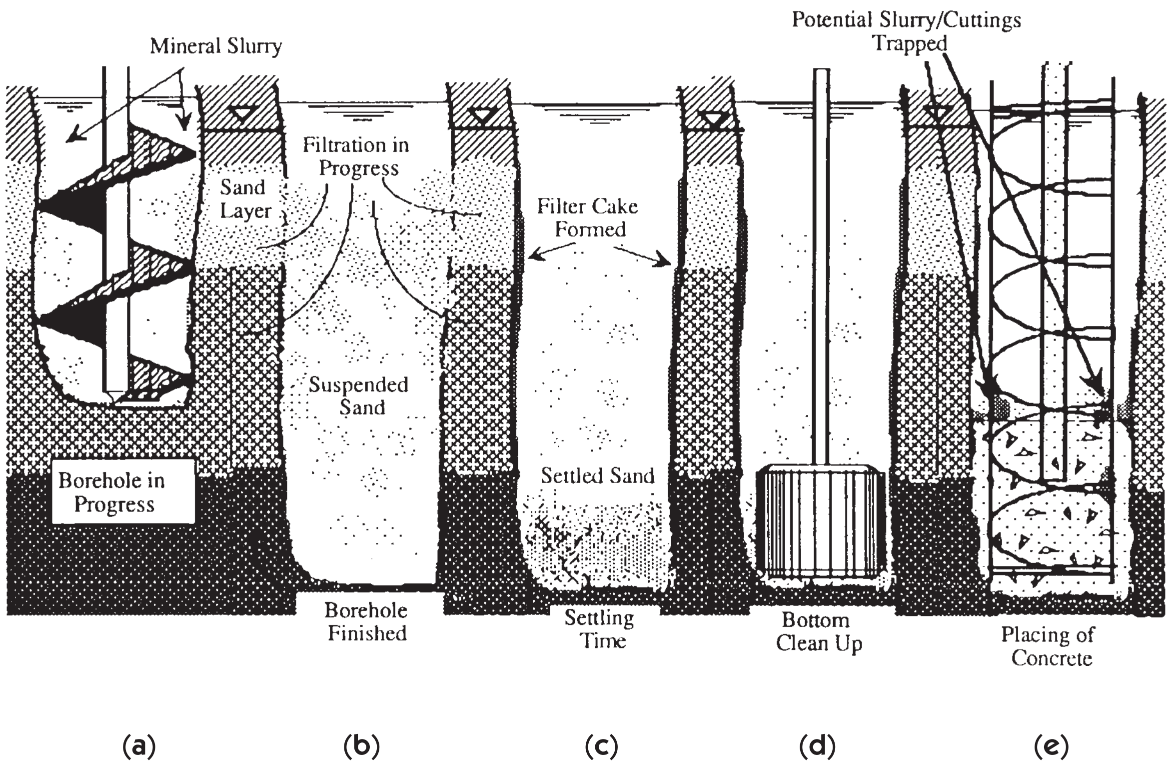


Figure 9-1: Slurry Displacement Method

Drilling slurries are generally introduced into the drilled hole as soon as groundwater or caving materials are encountered. As drilling continues to full depth, the drilling slurry is maintained at a constant level until the tip elevation of the drilled hole is reached (Figure 9-1(a)). Because the drilling operation mixes soil cuttings with the drilling slurry, it is necessary to remove the soil cuttings from the drilling slurry. Depending on the type of drilling slurry used, removing the soil cuttings may be accomplished by physically cleaning the drilling slurry, or by allowing a settlement period for the soil cuttings to settle out of the drilling slurry. Depending on the type of drilling slurry used, a process called filtration may also take place. Filtration results in the formation of a filter cake along the sides and bottom of the drilled hole. Figures 9-1(b) and 9-1(c) show the process of filtration and the cleaning of the soil cuttings from the drilling slurry. If the drilling slurry is cleaned such that it's physical properties are within the specified limits for the particular type of drilling slurry, the bottom of the drilled hole is cleaned of any settled materials using a cleanout bucket (Figure 9-1(d)). Since the action of the cleanout bucket may cause soil cuttings to recontaminate the drilling slurry, cleaning the bottom of the drilled hole and the drilling slurry may take several iterations. Additional cleanings of settled materials from the bottom of the drilled hole may be performed with a cleanout bucket, pumps, or an airlift. After the final cleaning has been accomplished and prior to concrete placement, the drilling slurry is retested to make sure its properties are within the specified limits. Once the drilling slurry is ready, the rebar cage may be placed. Concrete is then placed, either by a rigid tremie tube or by a rigid pump tube delivery system. Concrete is placed through the tube(s), starting at the bottom of the drilled hole (Figure 9-1(e)). The tip of the rigid delivery tube is maintained at least 10 feet below the rising head of concrete. As concrete is placed, the displaced drilling slurry is pumped away from the hole and prepared for reuse or disposal. Concrete placement continues until the head of concrete rises to the top of the pile and is then wasted until all traces of settled material or drilling slurry contamination in the concrete are no longer evident.

Principles of Slurry Usage

One of the ways drilling slurries function is by what is known as the "positive effective stress" principle (Figure 9-2). Essentially, this means that the drilling slurry produces stress on the sides of the drilled hole due to fluid pressure applied by differential head. This induced stress is produced by maintaining the level of the drilling slurry as high as possible (usually at least 5 feet) above the groundwater level in the drilled hole. In cases where the groundwater level is very close to the ground surface, use of a surface casing may be necessary to ensure positive effective stress is developed on the sides of the drilled hole.

Another way drilling slurries function is by the "filtration" principle. When drilling slurry is applying fluid pressure to the sides of the drilled hole, some of the drilling slurry and soil cuttings bonded to the drilling slurry may be forced into the ground formation. When this material enters the formation, particles of the drilling slurry may be trapped or "filtered" by the individual soil grains of the formation. This results in the development of filter cakes, referred to as "mudcakes" if a mineral slurry is used, or "gelcakes" if a polymer slurry is used, on the sides of the drilled hole. These filter cakes help to temporarily stabilize the sides of the drilled hole.

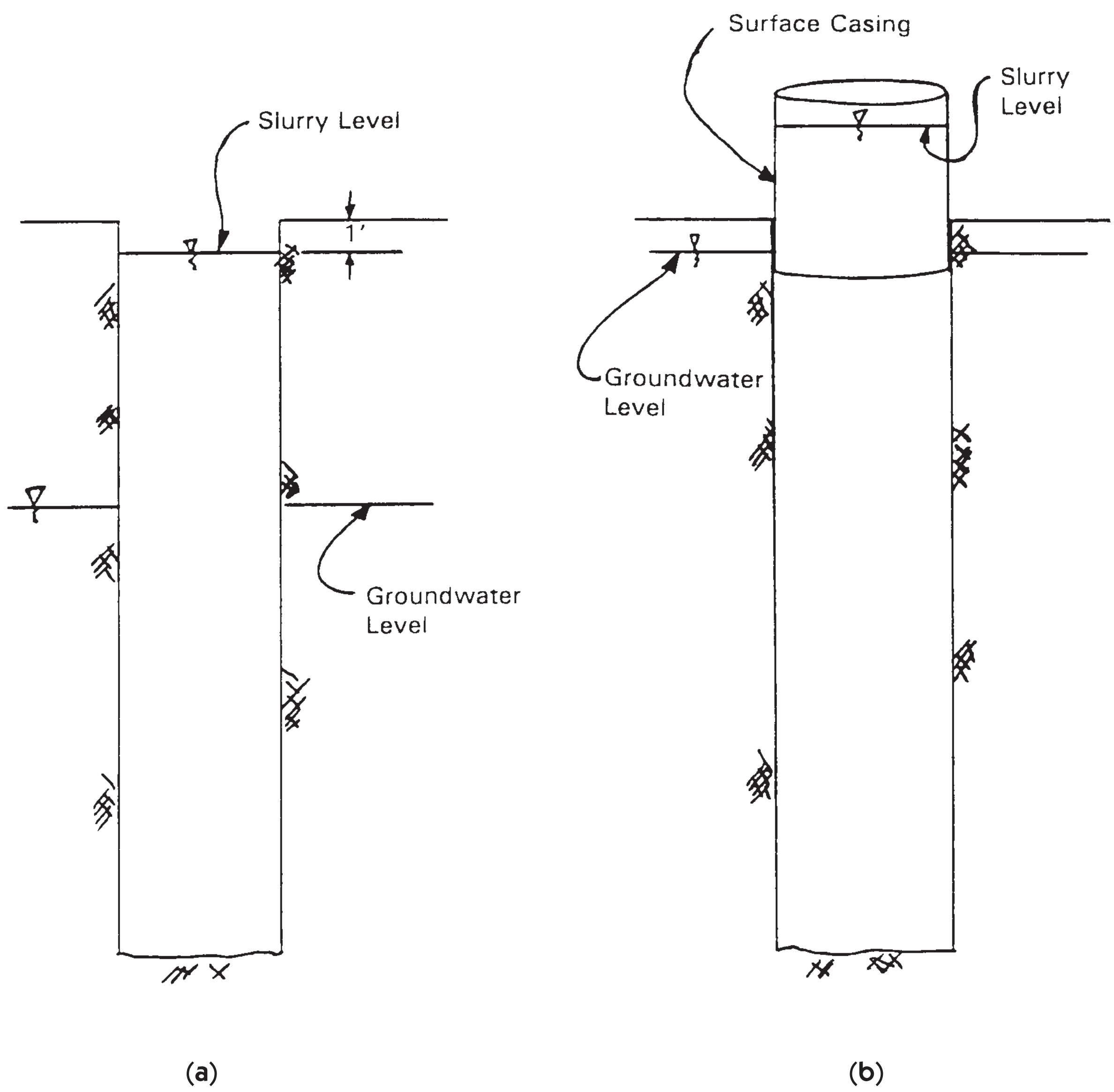


Figure 9-2: Positive Effective Stress

The filtration process is dependent upon many variables. These include the nature of the ground formation, the amount of time the drilling slurry is in the drilled hole, the presence of contaminants in the ground formation or groundwater, and the chemical additives used in the drilling slurry, just to name a few. In general, the nature of the ground formation and the amount of time the drilling slurry is in the drilled hole are the most important variables.

The nature of the ground formation has an effect on the thickness of the filter cake that develops on the sides of the drilled hole. In general, thicker cakes will form in looser ground formations, such as open sands and gravels. Because the pore spaces between the individual soil grains are larger in looser ground formations, the drilling slurry particles that are driven into the ground formation by positive effective stress tend to flow past the soil grains (Figure 9-3(a)). However, the drilling slurry particles will build up against the exposed faces of the soil grains. This build-up is capable of forming a thick filter cake on the sides of the drilled hole in a short period of time. In tighter ground formations, such as dense sands and cohesive soils, the pore spaces between the individual soil grains are much smaller. The drilling slurry particles tend to fill in the pore spaces (Figure 9-3(b)). Once the pore spaces are filled, drilling slurry cannot be forced into the ground formation by positive effective stress. This causes the build-up of filter cake to cease, resulting in a thinner filter cake build-up than would be observed in looser ground formations.

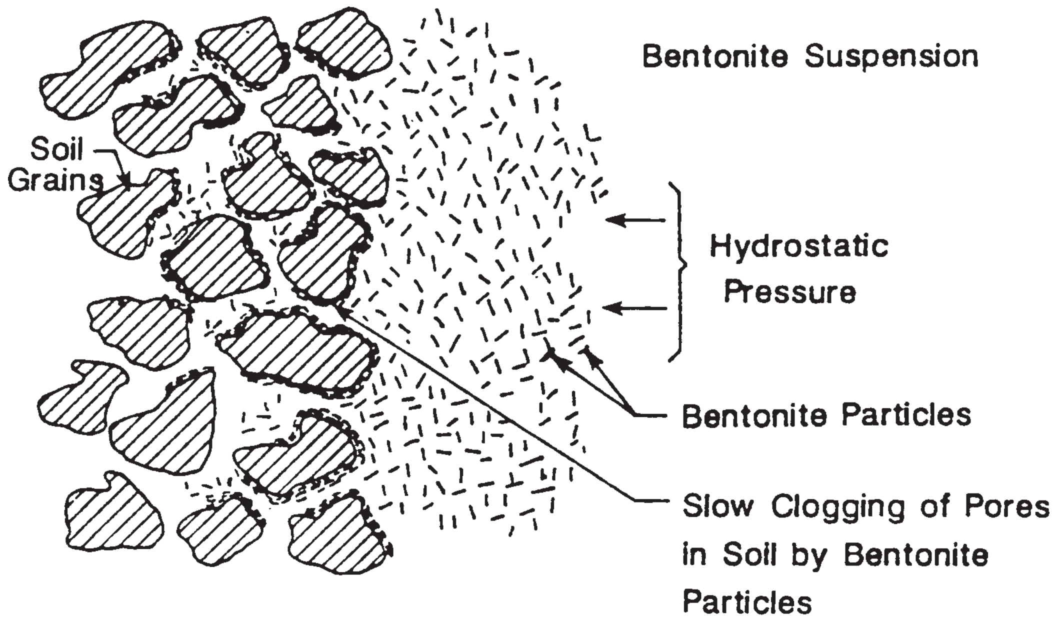


Figure 9-3(a): Filtration – Loose Ground Formation

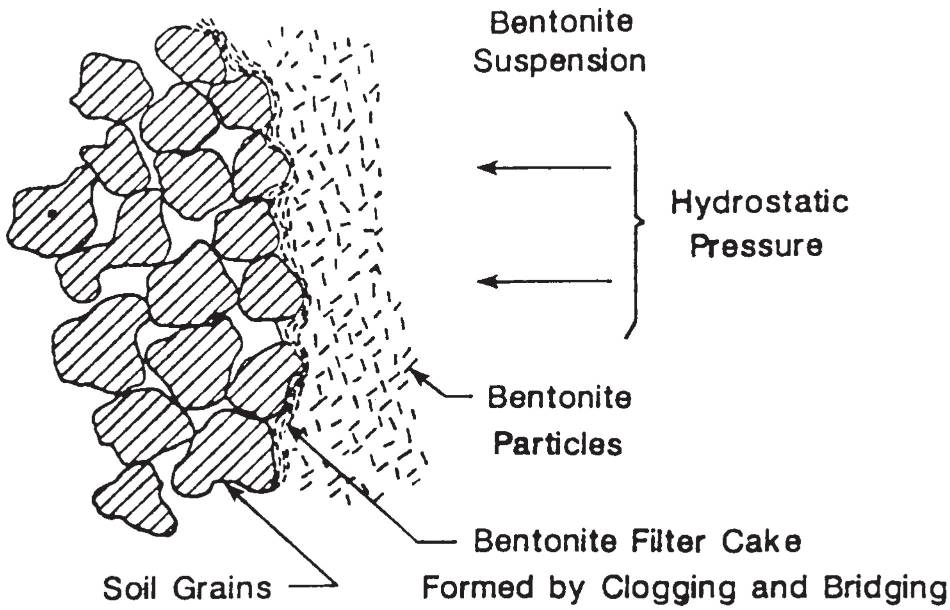


Figure 9-3(b): Filtration – Tight Ground Formation

The amount of time that the drilling slurry is in the drilled hole has a direct effect on the thickness of the filter cake that develops on the sides of the drilled hole. Since positive effective stress is a continuous phenomenon, the build-up of filter cake will continue so long as the pore spaces between the soil grains have not filled in. In general, the longer the drilling slurry is present in the drilled hole, the more filter cake will accumulate on the sides of the drilled hole. Sometimes this results in the presence of excess filter cake build-up, which must be removed before concrete can be placed in the drilled hole.

The important thing to remember about filtration is that the filter cake helps to temporarily stabilize the sides of the drilled hole before concrete is placed. Filter cake is not meant to be left in place during concrete placement operations. If the filter cake is thin enough, the rising column of concrete will scrape it off the sides of the drilled hole. However, if the filter cake has excessive thickness, the rising column of concrete may not scrape all of it off the sides of the drilled hole. The remaining filter cake may act as a slip plane between the pile concrete and the sides of the drilled hole, resulting in the reduced skin friction capability of the pile.

Sampling and Testing Drilling Slurry

Sampling and testing of drilling slurry is an important quality control requirement. Responsibility for testing and maintaining a drilling slurry of high quality is placed on the Contractor by the contract specifications.

The apparatus used to sample drilling slurry must be capable of sampling the drilling slurry at a given elevation in the drilled hole without being contaminated by drilling slurry at a different location as the sampler is removed from the drilled hole. This is necessary because the contract specifications require the drilling slurry to be sampled at different levels in the drilled hole. The sampler must also be large enough to contain enough drilling slurry to perform all the required tests. The apparatus generally consists of a hollow tube with caps positioned above and below the tube on a cable that is used to lower the sampler into the drilled hole (Figure 9-4). Once the sampler has been lowered to the desired level, the drilling slurry contained in the hollow tube at that level is contained by activating the caps so that the ends of the tube are sealed. The sampler is then removed from the drilled hole and the drilling slurry contained is tested.

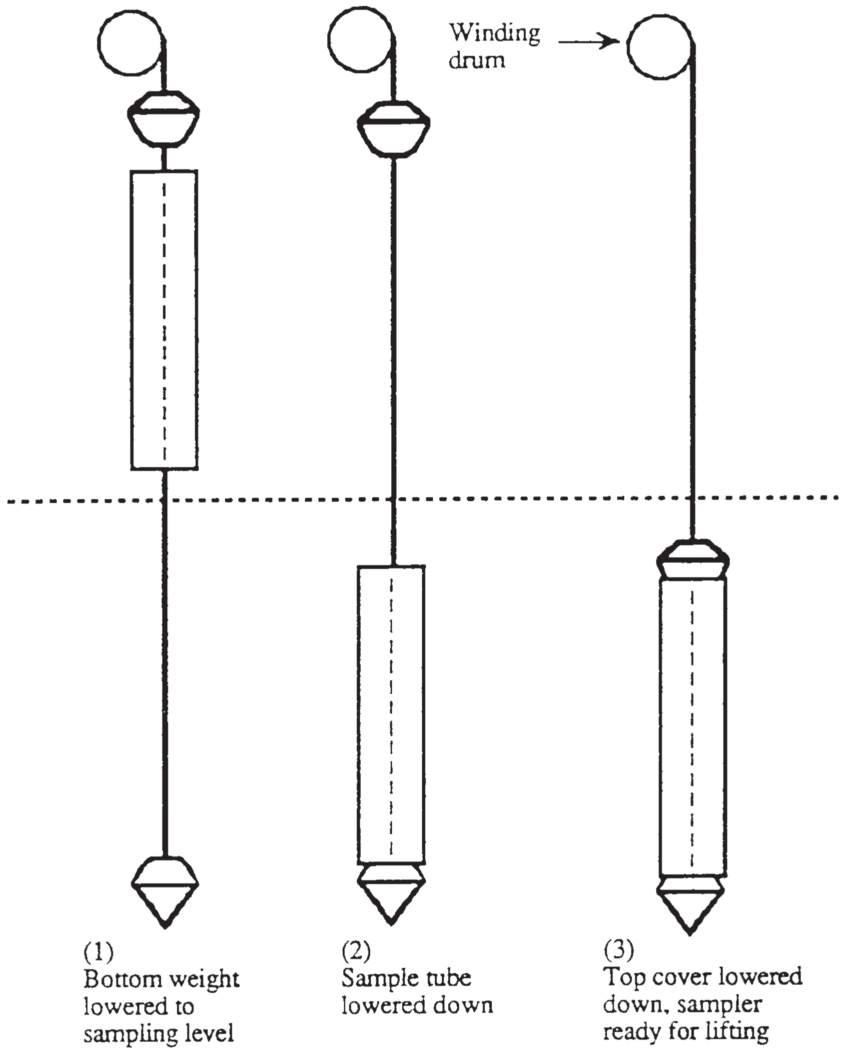


Figure 9-4: Slurry Sampler Schematic

One of the responsibilities of the Contractor is to verify that the sampler used seals properly. The Structure Representative may require the Contractor to verify this before allowing the construction of slurry displacement piles to commence.

The primary engineering reason for testing drilling slurries is to make sure that no suspended material in the drilling slurry settles out during concrete placement. A secondary reason for testing drilling slurries is to control their properties during the drilling of the hole. This helps to stabilize the drilled hole. Drilling slurries that have physical properties within the parameters described in the contract specifications should have negligible settlement of suspended materials during concrete placement provided the rebar cage and concrete are placed promptly.

The contract specifications set parameters for some of the physical properties of drilling slurries. The four specified physical properties are density, sand content, pH, and viscosity. These are described in the following paragraphs.

Density

Density, or unit weight, is a function of the amount of solids held in suspension by the drilling slurry. Since mineral slurries will hold solids in suspension for long periods, the allowable density value is higher than that permitted for polymer slurries and water, which do not hold solids in suspension as well. The density of the drilling slurry may be affected by its viscosity since a more viscous fluid will suspend more solids. The reason for having an upper limit on the allowable density value is that drilling slurries with higher densities are unstable with respect to their ability to suspend solids. These solids could settle out during concrete placement and cause pile defects.

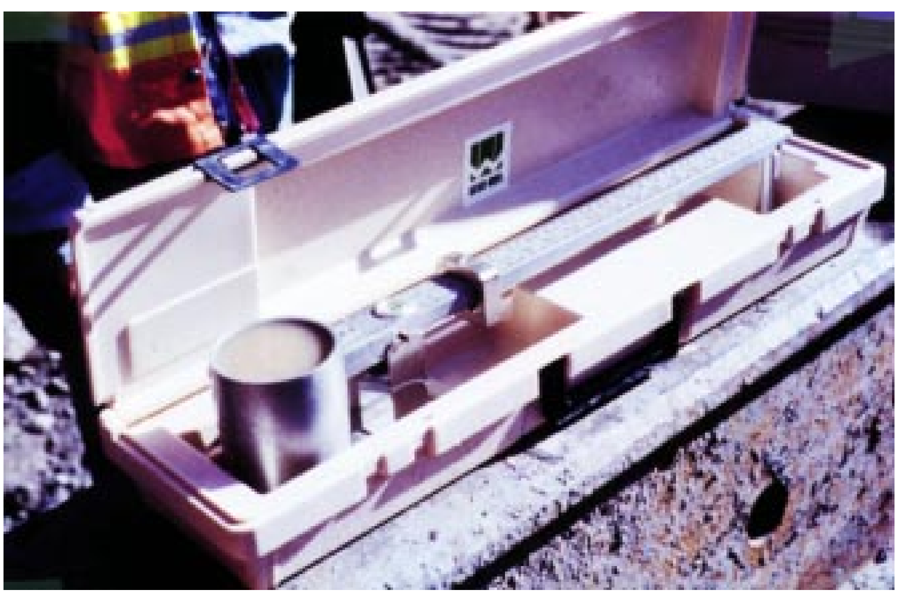


Figure 9-5: Density Test Kit

Density is tested using the test kit shown in Figure 9-5 in conformance with the test method described in American Petroleum Institute (API) Recommended Practice 13B-1, Section 1. This test method is included in Appendix G.

Sand Content

Sand content is an important parameter to keep under control, particularly just prior to concrete placement. Sand is defined as any material that will not pass through a No. 200 sieve. Since mineral slurries will hold sand particles and other solids in suspension, the allowable sand content value is higher than that permitted for polymer slurries and water, which do not hold these solids in suspension as well. The primary reason for setting an upper limit on the sand content value is to prevent significant amounts of sand from falling out of suspension during concrete placement. A secondary reason for setting an upper limit on the sand content value is that high sand content can increase the amount of filter cake on the sides of the drilled hole in mineral slurries. This increased filter cake might have to be physically removed before concrete could be placed in the drilled hole. Allowing the filter cake to remain would decrease the skin friction value of the pile, which is not desirable.

Figure 9-6: Sand Content Test Kit

Sand content is tested using the test kit shown in Figure 9-6 in conformance with the test method described in API Recommended Practice 13B-1, Section 5. This test method is included in Appendix G.

pH Value

The pH value of a drilling slurry is important to ensure its proper functioning. Mineral slurries which have pH values outside the allowable range will not fully hydrate the clay mineral and will not develop the expected viscosity. Polymer slurries which are mixed in water having pH values outside the allowable range may not become viscous at all. It cannot be assumed that drilling slurries that are mixed in a controlled environment (such as in a mixing tank) will not be affected by acids and organic material from the groundwater or the soil. Mineral slurries may deflocculate and fail to form a filter cake if the slurry becomes too acidic or too alkaline. Polymer slurries may lose their viscosity and their ability to stabilize the sides of the drilled hole if the slurry becomes too acidic or too alkaline.

The pH value of a drilling slurry is tested using either a pH meter or pH paper.

Viscosity

Viscosity refers to the "thickness" of the drilling slurry. This property is measured to prevent the drilling slurry from becoming too thick and suspending more solids than permitted, which would affect the density and sand content values. On the other hand, a drilling slurry may require a higher viscosity during drilling to permit the formation of filter cake or to stabilize the sides of the drilled hole in loose ground formations such as gravels. A thinner drilling slurry would tend to flow through a loose ground formation without building a filter cake or providing stability. After the hole is drilled and a filter cake has formed or the sides of the drilled hole have stabilized, the drilling slurry can be thinned as required prior to concrete placement.

Figure 9-7: Marsh Funnel Viscosity Test Kit

The viscosity of a drilling slurry is tested using the test kit shown in Figure 9-7 in conformance with the test method described in API Recommended Practice 13B-1, Section 2.2. This test method is included in Appendix G.

Types of Slurry

It is important to note that the type of drilling slurry to be used will depend on the ground conditions encountered. Use of different types of drilling slurries may be necessary to drill through different types of ground formations. It is conceivable that different types of drilling slurries may need to be used on the same contract because of varying ground conditions within the highway right-of-way. Some of the factors that influence the decision of what type of drilling slurry to use include economics, ground and groundwater contamination, ground temperature, air temperature, and the type of ground formation being drilled through.

Ground conditions can also have an effect on drilling slurry behavior. Some of these include acidity or alkalinity of groundwater, grain size of the soil, velocity of groundwater flow through the ground formation, cementation and cohesion of soil, and the presence of rock or clay structures in the ground formation. The drilling slurry's physical properties can be adjusted to account for some of these conditions, or chemical additives may be necessary.

Because most drilling slurries are difficult and expensive to dispose of, most drilling contractors will want to reuse the drilling slurries. Occasionally, contractors will want to reuse the drilling slurry on another pile after completion of the previous pile. Some contractors may want to reuse the drilling slurry on another contract.

The contract specifications do not prohibit the reuse of drilling slurry. However, the drilling slurry must meet the physical property requirements of the contract specifications. Drilling slurries will degrade over time (usually measured in months). If a Contractor proposes to reuse a drilling slurry from a different contract, the Structure Representative may want to have the physical properties of the drilling slurry tested prior to placement in the drilled hole.

The reuse of drilling slurries requires careful planning on the Contractor's part. Drilling slurries must be cleaned before they are reused. For mineral slurries, this is accomplished through the use of desanding units and chemical additives. For polymer slurries, this is accomplished by allowing the contaminants to settle out.

The types of drilling slurries that are permitted for use by Caltrans (as of 1994) are detailed in the following sections. Three types of drilling slurries are permitted: water, mineral, and synthetic polymer.

Water

Water may be a suitable drilling slurry under the right conditions. Most drilling contractors will try to use water as a drilling slurry if the ground conditions are right because it is inexpensive. However, use of water as a drilling slurry is limited to ground formations that are strong enough not to deform significantly during drilling. The water level in the drilled hole must be maintained at least 5 feet above the groundwater level in order to maintain positive effective stress on the sides of the drilled hole. This is the only means of stabilization provided to the sides of the drilled hole since water does not control filtration.

The contract specifications state that water may only be used as a drilling slurry when temporary casing is used for the entire length of the drilled hole. Although water was permitted to be used as a drilling slurry in the recent past by the contract specifications, history has shown that water was inappropriately chosen as a drilling slurry for use in holes drilled in unstable ground formations by some contractors for economic reasons. This resulted in many defective piles that required repair.

The question that may arise from this limitation is why the contract specifications allow the use of water as a drilling slurry at all. Retaining the limited use of water as a drilling slurry allows a Contractor, who attempts to dewater a drilled hole using temporary casing and is unable to do so for whatever reason, to have the option of using the water in the drilled hole as a drilling slurry to prevent quick conditions at the bottom of the drilled hole and to be able to place concrete.

The physical properties of water used as a drilling slurry are not as critical as with other types of drilling slurries. Water is capable of suspending sand and silt only for short periods, usually less than 30 minutes. This allows soil cuttings to settle to the bottom of the drilled hole fairly rapidly. Since the pH of water is not important and water will not typically become more viscous, the contract specifications set parameters for density and sand content only. Testing these parameters verifies that most of the suspended material has settled before final cleaning of the drilled hole and concrete placement.

Water used as a drilling slurry can be easily disposed of on site after settlement of all suspended materials has occurred unless the water has been contaminated by hazardous materials.

Mineral

Mineral slurries are processed from several different types of clay formations. Although there are a number of different types of clay formations available, the most commonly used consist of Bentonite and Attapulgite clay formations.

Bentonite is a rock composed of clay minerals, named after Fort Benton, Wyoming, where this particular type of rock was first found. It is processed from the clay mineral Sodium Montmorillonite, which hydrates in water and provides suspension of sands and other solids.

Bentonite slurry is a mixture of powdered bentonite and water. Bentonite slurry will flocculate (destabilize) in the presence of acids and ionized salts and is not recommended for ground formations where salt water is present without the use of chemical additives.

Figure 9-8: Bentonite Slurry

Attapulgite comes from a clay mineral that is native to Georgia. It is processed from the clay mineral Palygorskite, and is similar in structure to Bentonite. However, it does not hydrate in water and will not flocculate in the presence of acids and ionized salts and can be used in ground formations where salt water is present. Due to the expense of transport and the relative rarity of use of this type of drilling slurry in California, it is unlikely that this type of mineral slurry will be encountered on Caltrans projects.

Mineral slurries stabilize the sides of the drilled hole by positive effective stress and by filtration. Mineral slurries will penetrate deeper into more open formations, such as gravels, and will form thicker filter cakes in these formations. While filtration is desirable, a thick filter cake is not desirable because it is necessary to remove it before concrete placement. Continuous agitation or recirculation of the mineral slurry will help reduce the thickness of the filter cake by reducing the amount of suspended material in the mineral slurry.

The contract specifications require the removal of "caked slurry" from the sides and bottom of the drilled hole before concrete is placed. Office of Structure Construction policy is that "caked slurry" is considered to be an excessively thick filter cake that has formed on the sides or bottom of the drilled hole. Because the amount of filter cake that forms on the sides and bottom of the drilled hole is dependent upon so many variables and because research of the effect of filter cake on the ability of the pile to transfer load through skin friction has not been completed, current Office of Structure Construction policy defines excessively thick filter cake as a filter cake that has formed in a drilled hole where mineral slurry has been continuously agitated or recirculated in excess of 24 hours *or* a filter cake that has formed in a drilled hole where mineral slurry has been unagitated in excess of 4 hours. Due to the fact that each site is different, some engineering judgement should be applied before implementing this policy. There are other indicators that can be used to assist the Engineer in making a judgement on the amount of filter cake present on the sides and bottom of the drilled hole. One indicator is the level of mineral slurry in the drilled hole. If the mineral slurry level is difficult to maintain at the required level in the drilled hole, this is an indicator that the mineral slurry is continuously being driven into the ground formation through the sides of the drilled hole. This means that filter cake build-up is continuing and it is likely that the thickness of the filter cake is excessive. However, if the mineral slurry level is stable in the drilled hole, this is an indicator that the mineral slurry has clogged up the ground formation on the sides of the drilled hole. This means that the filter cake build-up would have ceased and it is likely that the thickness of the filter cake is *not* excessive. Removal of excessively thick filter cake is accomplished by slightly overboring the full length of the drilled hole.

The contract specifications require that mineral slurries be mixed and fully hydrated in mixing tanks prior to placement in the drilled hole. Mixing and hydration of mineral slurries usually requires several hours. One way to determine that the mineral slurry is thoroughly hydrated is to take Marsh funnel viscosity tests at different time intervals. In general, mineral slurries will achieve their highest viscosity value when they have fully hydrated. Once the viscosity test values have stabilized at their highest level, the mineral slurry can be assumed to be fully mixed and fully hydrated.

The physical properties of the mineral slurry should be carefully monitored while the mineral slurry is in the drilled hole. The mineral slurry's density, sand content, and viscosity should be tested and the values maintained within the limits stated in the contract specifications to prevent excessive suspended materials and to keep the filter cake thickness on the sides of the drilled hole to a minimum. The mineral slurry's pH should be tested and maintained within the limits stated in the contract specifications to prevent flocculation or destabilization. It should be noted by the Engineer that it will usually take the Contractor some time to get the mineral slurry's properties within the limits stated in the contract specifications. The important factor is to verify that the mineral slurry's properties are within the limits stated in the contract specifications prior to concrete placement.

While mineral slurries are present in the drilled hole, they must be agitated in order to maintain their physical properties and to reduce the amount of filter cake buildup on the sides of the drilled hole. In order to accomplish this, the contract specifications require mineral slurries to be agitated by either of two methods: (1) the mineral slurry is to be continuously agitated within the drilled hole, or (2) the mineral slurry is to be recirculated and cleaned. Either of these methods will provide the necessary continuous agitation of the mineral slurry. The method that is chosen will depend on the cleanliness of the mineral slurry in the drilled hole. This is typically influenced by the ground conditions encountered.

Recirculation and cleaning of mineral slurries is accomplished by removing the mineral slurry from the drilled hole, running it through specialized cleaning equipment, and then placing the cleaned mineral slurry back in the drilled hole. To meet all of the specification requirements, a slurry "plant", which is approximately the size of a railroad boxcar, must be located adjacent to the work area (Figure 9-9). The slurry plant contains screens, shakers, desanding centrifuges (Figure 9-10), and agitators, and is capable of mixing, storing, and cleaning the mineral slurry. Figure 9-11 shows a typical recirculation and cleaning process. It is very important to remove the mineral slurry from the *bottom* of the drilled hole. This is because excessive amounts of suspended materials will eventually settle to the bottom of the drilled hole. These materials must be removed in order to fully clean the mineral slurry. Typically, it will take several hours to completely clean the mineral slurry of sand and other suspended materials.

Figure 9-9: Mineral Slurry Plant

Figure 9-10: Desanding Centrifuges

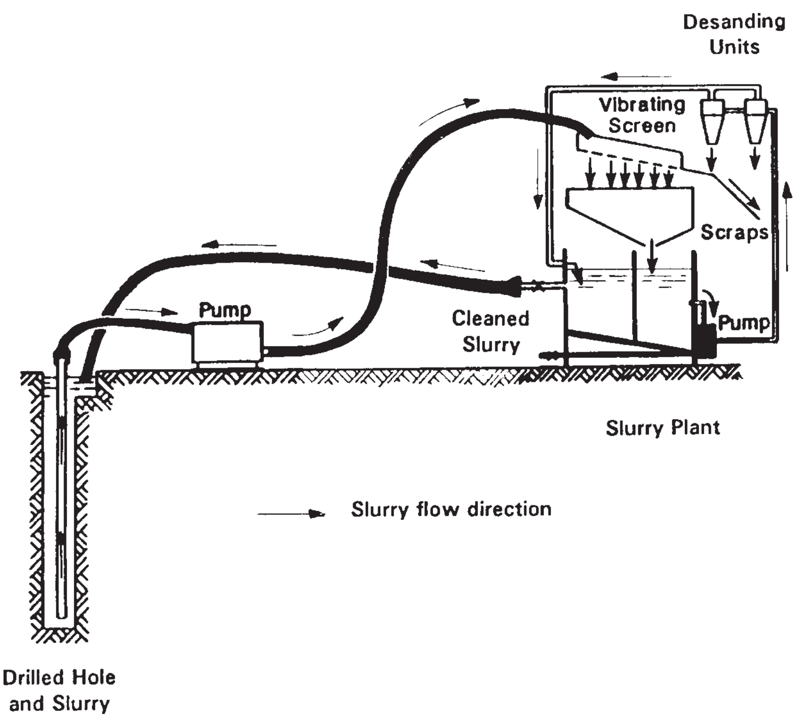


Figure 9-11: Recirculation and Cleaning Schematic

Usually, in order for the mineral slurry to meet the physical property requirements of the contract specifications, the mineral slurry will require recirculation and cleaning during and after the drilling operation. Occasionally without any action on the part of the Contractor, the mineral slurry will meet the physical property requirements of the contract specifications during and after the drilling operation, in which case continuous agitation of the mineral slurry in the drilled hole is acceptable. However, the contract specifications also require that any mineral slurry which is continuously agitated in the drilled hole and exceeds the physical property requirements *must be recirculated and cleaned*.

Should the mineral slurry's properties change dramatically during the drilling operation, there are many chemical additives available that can reduce the filter cake thickness, lower the mineral slurry's pH, and increase the mineral slurry's viscosity. Additives that reduce the filter cake thickness and increase the mineral slurry's viscosity include organic colloids and lignosulfonates. Additives that lower the mineral slurry's pH include soda ash and pyrophosphate acid. Additives that decrease the mineral slurry's viscosity include tanins and polyphosphates. Caltrans has little experience with chemical additives and their use should be discussed with the Office of Structural Foundations and the Office of Structure Construction in Sacramento. In general, modifying the pH of the mineral slurry with chemical additives is not a problem.

Mineral slurries may be used in most types of ground formations. They work best in cohesionless sands and open gravels. Caution must be taken when using mineral slurries in cohesive materials because they may contain clays that can be incorporated into the mineral slurry and rapidly change the mineral slurry's physical properties. In addition, cohesive materials can reduce filtration and filter cakes may not form.

Disposal of mineral slurries can be difficult. Due to their particulate nature, they are hazardous to aquatic life and cannot be disposed of on site or at locations where they can enter State waters. The contract specifications require that any materials resulting from the placement of piles under mineral slurry be disposed of outside the highway right-of-way in accordance with Section 7-1.13 of the Standard Specifications. Because they often contain chemical additives, mineral slurries can be considered to be hazardous materials which must be disposed of in landfills. This can be very expensive and can defeat the economic advantage of using the slurry displacement method over other means of construction of CIDH piles.

Polymer

Polymer drilling slurries have been gaining wide acceptance in the construction industry over the last 10 years. The main advantage of polymer slurries is that they are easier and cheaper to dispose of than mineral slurries and do not require slurry plants to physically clean the slurry. Polymer slurries are grouped into three groups: (1) naturally occurring polymers, (2) semi-synthetic polymers, and (3) synthetic polymers. The synthetic polymers currently consist of two types: (1) emulsified Partially Hydrolyzed Polyacrylamide, Polyacrylate (PHPA) polymers, and (2) dry vinyl polymers.

Research has been performed at the University of Houston, by the various polymer slurry manufacturers, and by Caltrans on the effect of polymer slurries on rebar bond, pile skin friction, and concrete contamination. Although incomplete, this research has resulted in the approval of some polymer slurries for use on Caltrans contracts. As of 1994, the contract specifications permit the use of two brands of synthetic polymer slurries. These are Super Mud, manufactured by PDS Company and SlurryPro CDP™, manufactured by KB Technologies, LTD.

Super Mud is an emulsified PHPA polymer type of synthetic polymer slurry. Emulsified PHPA polymers rely on the positive effective stress principle because they do not control filtration in open ground formations and will not form a filter cake on the sides of the drilled hole. However, the polymer chains in the drilling slurry do enter the ground formation and bond to the individual soil grains. This helps to stabilize the sides of the drilled hole. Continuous addition of drilling slurry may be required in order to stabilize the level of the drilling slurry in the drilled hole. Because a filter cake is not formed, maintaining the level of the drilling slurry well above the groundwater level is essential. A liquid form of Super Mud is currently approved for use on Caltrans projects. No other form is approved.

Figure 9-12: *SuperMUD* Container

SlurryPro CDP™ is a dry vinyl polymer type of synthetic polymer slurry. Dry vinyl polymers also rely on the positive effective stress principle. However, they also control filtration and will form a filter cake in the form of a thin gel membrane on the sides of the drilled hole. Removal of this gel membrane is not required because it is not considered to be "caked slurry". Unlike the filter cake formed by mineral slurries, according to the manufacturer, the gel membrane may actually improve concrete bonding to the sides of the drilled hole. Enough research has not been done to validate this claim. A dry granular form of SlurryPro CDP™ is currently approved for use on Caltrans projects. No other form is approved.

Figure 9-13: *SlurryPro CDP* Container

Polymer slurries must be thoroughly mixed but do not require additional time to hydrate. This is because polymer slurries do not hydrate in water. Water used to mix with the emulsion PHPA polymer must have a pH in the range of 9 to 11 in order to properly disperse the polymer. A more acidic pH will cause the polymer slurry to flocculate and become ineffective. A mixing tank is usually required in order to regulate the water. The manufacturer of Super Mud recommends tank mixing, but mixing directly into the drilled hole by introducing the Super Mud fluid into the flow of water is also acceptable to the manufacturer. Dry vinyl polymer in granular form is not as sensitive to the pH of water and will disperse in a more acidic environment and therefore can be mixed directly in the drilled hole. The manufacturer of SlurryPro CDP™ also recommends tank mixing, but mixing directly into the drilled hole by sprinkling the dry granules into the flow of water entering the drilled hole is also acceptable to the manufacturer.

The physical properties of polymer slurries should be carefully monitored during drilling of the hole and before concrete placement. Because polymer slurries in general do not suspend particles, the permissible density and sand content values are much lower than those allowed for mineral slurries. The density and sand content values should be tested and the values maintained within the limits stated in the contract specifications to allow for quick settlement of suspended materials. The polymer slurry's pH value should be tested and maintained within the limits stated in the contract specifications to prevent destabilization of the slurry. The allowable limits described in the contract specifications for density, sand content, and pH vary between Super Mud and SlurryPro CDP™ due to the extensive research that had been done by the manufacturers during the Caltrans approval process.

The polymer slurry's viscosity value has a higher level of importance than that of mineral slurry. The polymer slurry's viscosity value should be tested and maintained within the limits stated in the contract specifications to prevent destabilization of the sides of the drilled hole. However, polymer slurries at high viscosities may be capable of suspending sand particles for longer than expected periods, causing the density and sand content values to increase above their allowable limits. For this reason, caution must be practiced when using polymer slurries at high viscosities so that particulate settlement on the head of concrete during concrete placement can be prevented. The allowable limits described in the contract specifications for viscosity vary dramatically between Super Mud and SlurryPro CDP™. This is due to the extensive research that had been done by the manufacturers during the Caltrans approval process. In general, polymer slurries with very high viscosity values (> 70) are not approved for use during concrete placement because not enough research has been done to determine the effect of polymer slurries with such high viscosities on the perimeter load transfer capabilities between the pile concrete and the ground formation.

In general, polymer slurries will break down when they come in contact with concrete. This is advantageous as long as the polymer slurry is clean and the rising head of concrete is the only concrete in contact with the polymer slurry. However, if concrete is allowed to intermingle with the polymer slurry, the polymer slurry may break down and cause the sides of the drilled hole to destabilize.

The contract specifications also require the presence of a manufacturer's representative to provide technical assistance and advice on the use of their product before the polymer slurry is introduced into the drilled hole. The manufacturer's representative must be approved by the Engineer. Assistance on approval of a manufacturer's representative may be obtained from the Office of Structure Construction in Sacramento. The manufacturer's representative can provide assistance with polymer slurry property testing, can test the water to be used for contaminants that may adversely affect the properties of the polymer slurry and the stability of the drilled hole, and can give advice in the proper disposal of the polymer slurry. The manufacturer's representative may also recommend the use of chemical additives to adjust the polymer slurry to the existing ground conditions. Caltrans has little experience with chemical additives and their use should be discussed with the Office of Structural Foundations and the Office of Structure Construction in Sacramento before approval is given for their use. In general, modifying the pH of the polymer slurry with chemical additives is not a problem. The contract specifications also require the manufacturer representative's presence until the Engineer is confident that the Contractor has a good working knowledge of how to use the product, after which the manufacturer's representative can be released. This can usually be accomplished with the completion of one pile.

Polymer drilling slurries can be used in most types of ground formations. However, the contract specifications state that polymer slurries shall not be used in soils classified as "soft" or "very soft" cohesive soils. There are two reasons for this. First, polymer slurries will encapsulate and cause settlement of clay particles from the soil cuttings. These encapsulated clay particles are similar in appearance and size as sand particles and will cause excessively high false readings of the sand content test value. This problem may also occur in soils that are only slightly cohesive. To overcome this problem, the Contractor should use a dilute bleach solution instead of water to wash the fines through the #200 mesh screen during the sand content test. This will break up the encapsulated clay particles so they will wash through the #200 mesh screen. Second, as of 1994, the polymer slurry manufacturers have not completed the research necessary to show that their products function properly in soils defined as "soft" or "very soft" cohesive soils. If this research is successfully completed, the contract specifications may be amended to remove this limitation.

Disposal of polymer slurries is somewhat easier than disposal of mineral slurries. The manufacturers of the approved polymer slurries are attempting to get approval for different disposal techniques. However, until they do so, the contract specifications require all material resulting from the placement of piles, including drilling slurry, shall be disposed of outside of the highway right-of-way as described in Section 7-1.13 of the *Standard Specifications* unless otherwise permitted by the Engineer. The Engineer may allow disposal by other means if the proper permits are secured or permission is obtained from the appropriate regulatory agency. Other means of disposal include placing the polymer slurry in a lined drying pit and allowing it to evaporate. The dried solids then can be disposed of in a similar fashion as other jobsite spoils. Polymer slurries can also be broken down to the viscosity of plain water with chemical additives, allow time for solids to settle out, and then be disposed of as clarified waste water. Permission must be obtained from the responsible authority, usually the California Regional Water Quality Control Board or the local sanitation district, for this type of disposal. The dried solids can be disposed of as mentioned above.

Equipment

The equipment used to construct CIDH piles by the slurry displacement method is not much different than that used to construct CIDH piles by ordinary means. However, there are some differences in the drilling tools, drilling techniques, cleaning techniques, and use of casing.

The primary reason that modified drilling tools and drilling techniques are used has to do with the way drilling slurries work. The drilling contractor must be careful not to do anything that would disturb the positive effective stress provided by the drilling slurry on the sides of the drilled hole. The drilling tool can produce rapid pressure changes above and below it, similar to the effect of a piston, if it is lifted or lowered too quickly. When these pressure changes are produced, the drilled hole can collapse (Figure 9-14). This problem can be remedied through the use of drilling tools that allow the drilling slurry to pass through or around the tool during lifting and lowering. For augers, special steel teeth are added to overbore the drilled hole so the diameter of the drilled hole is larger than the diameter of the auger. For drilling buckets and cleanout buckets, special steel teeth are added to overbore the drilled hole, or the bucket itself may be vented. Even with these modifications, the drilling technique must be modified so that the drilling tool is not lowered or raised too rapidly through the drilling slurry.

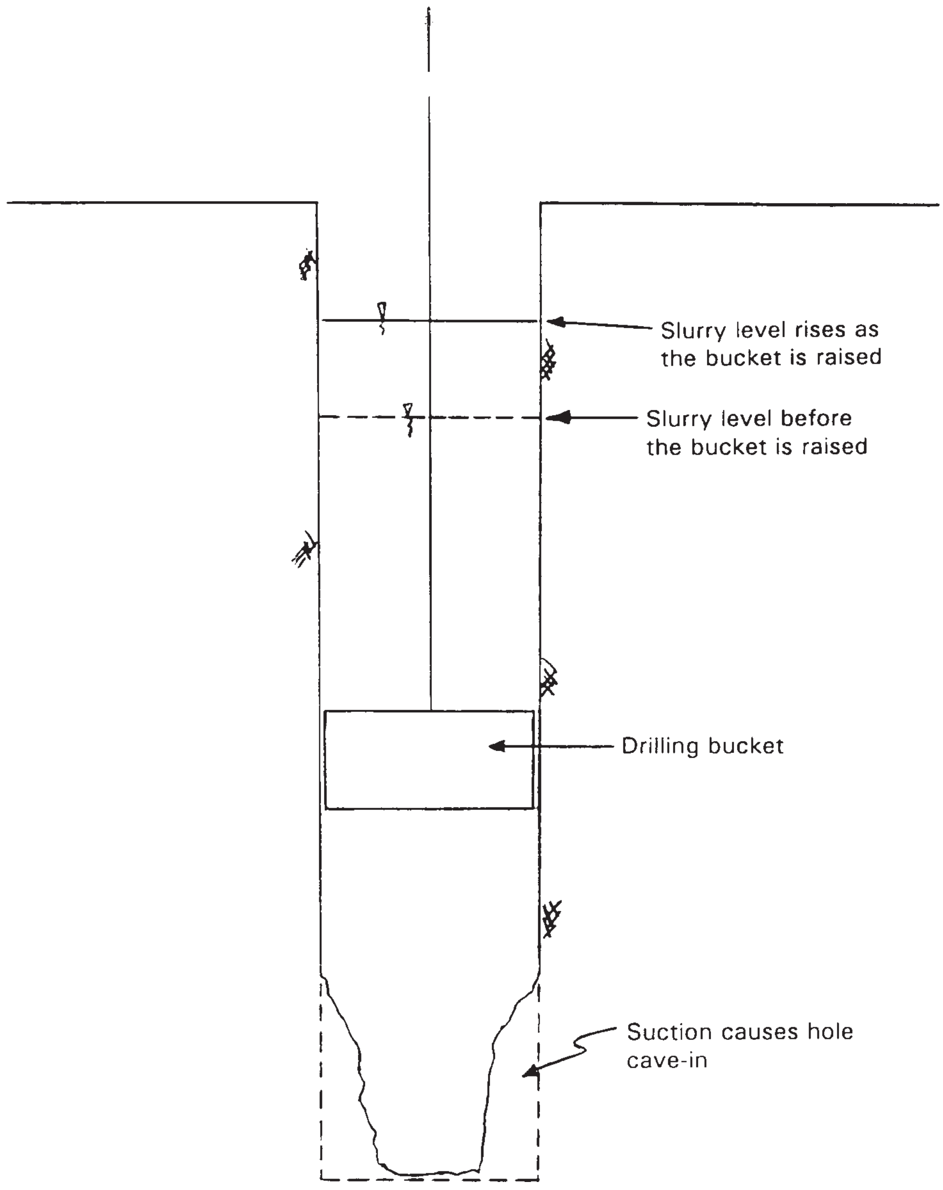


Figure 9-14: Hole Collapse induced by Pressure Changes

The techniques used to clean the bottom of the drilled hole are also modified for use in drilling slurries. The initial cleaning of the bottom of the drilled hole is done with a cleanout bucket so that the bottom of the drilled hole has a hard flat surface (Figure 9-15). However, as sand particles settle out of suspension in the drilling slurry, additional cleanings may be required. These additional cleanings can be accomplished with a cleanout bucket, the combined use of a cleanout bucket and pumps, or with a device known as an airlift (Figure 9-16). The airlift device operates with air that is supplied to the bottom of the drilled hole by an air compressor. This causes the settled sand particles to be lifted off the bottom of the drilled hole and vented.

Figure 9-15: Cleanout Bucket

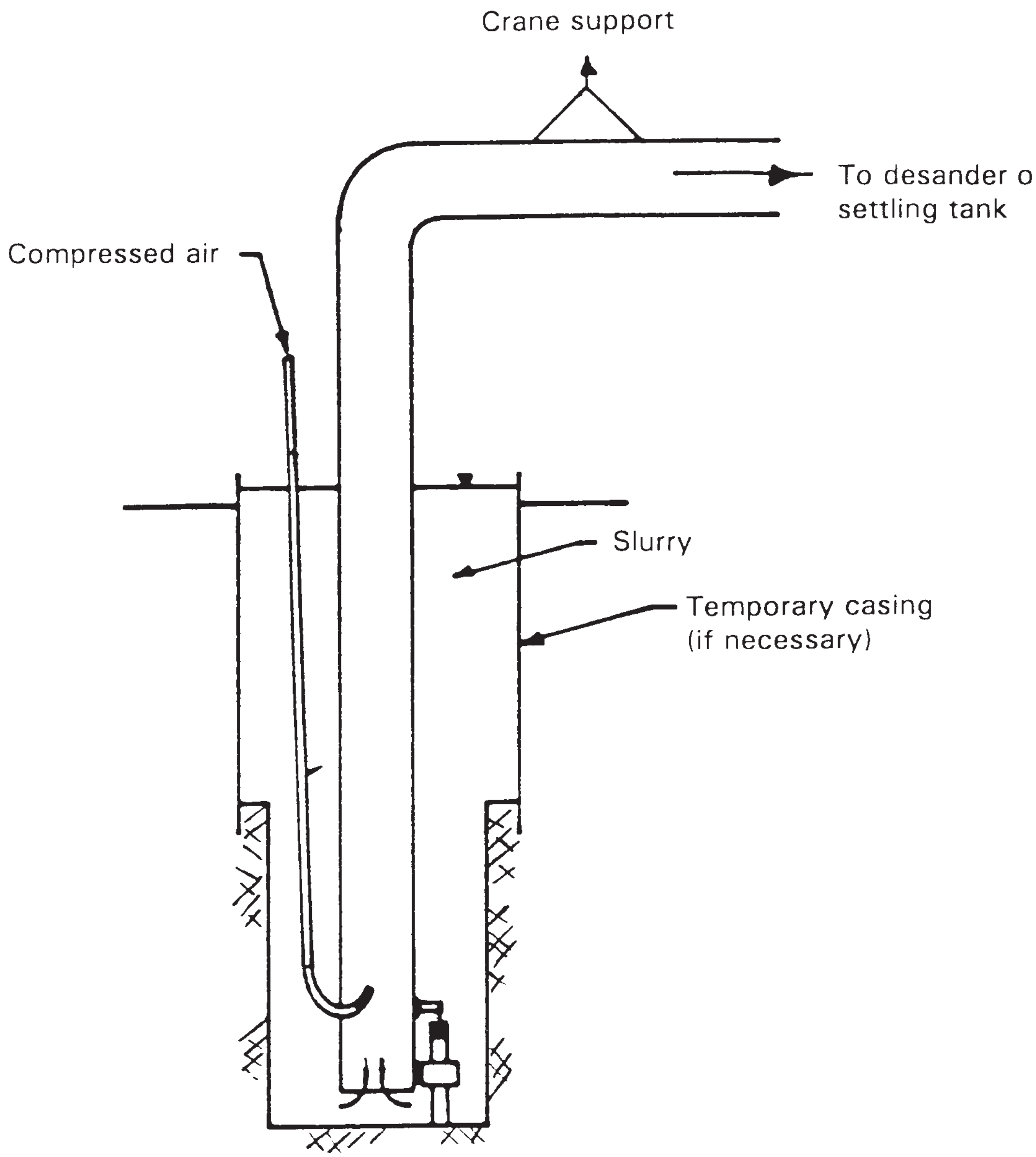


Figure 9-16: Airlift Schematic

The use of temporary casing may be appropriate in certain situations when the slurry displacement method is used. Temporary casing may be necessary if a dry loose material strata or a loose material strata with flowing groundwater are encountered during drilling (Figure 9-17). Even drilling slurries with viscosity values at the allowable maximum limit may not be able to stabilize a drilled hole in these situations. It may be necessary to place temporary casing only where the dry loose material strata or the loose material strata with flowing groundwater is located and use mineral or polymer drilling slurries to stabilize the remainder of the drilled hole. Another option is to place full length temporary casing in the drilled hole and use the water as the drilling slurry in order to avoid a quick condition at the bottom of the drilled hole.

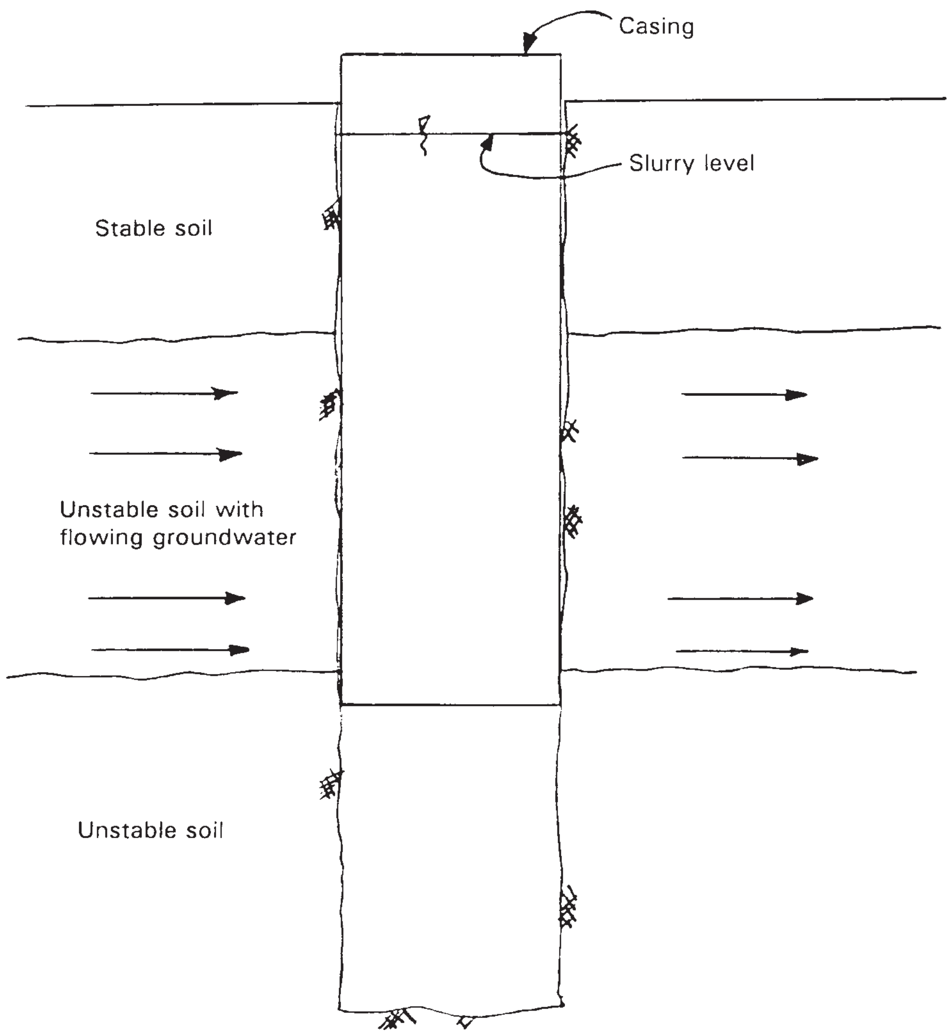


Figure 9-17: Use of Casing

Concrete Placement

The concrete placement operation for a CIDH pile constructed under drilling slurry is an operation that requires much preplanning. Before the work begins, the contract specifications require that the concrete mix design meet the trial batch requirements for compressive strength concrete. These requirements are described in Section 90-9 of the *Standard Specifications*. The concrete mix must contain at least 658 pounds of cement per cubic yard. It is also important to compare the maximum aggregate size in the concrete mix design to the bar reinforcement spacing. The bar spacing should be no less than five times the maximum aggregate size. The Project Designer should be contacted if this is not the case. A concrete test batch is also required to show the concrete mix design meets the consistency requirements of the contract specifications. The concrete consistency requirements are to ensure that the concrete will remain fluid throughout the length of the pour. The Engineer shall not allow the Contractor to exceed the maximum allowable water requirement to achieve this goal. Chemical admixtures will most likely be necessary. It is also important for the concrete mix to be properly proportioned to prevent excess bleedwater due to the high fluidity of the concrete.

The method of concrete placement should not permit the intermingling of concrete and drilling slurry. The contract specifications allow placement of concrete through rigid tremie tubes, or through rigid tubes connected directly to a concrete pump. In order to prevent intermingling of concrete and drilling slurry, the concrete placement tubes must be capped with a watertight cap or plugged such that the concrete will not come into contact with the drilling slurry within the concrete placement tube. The cap or plug should be designed to release when the placement tube is charged with concrete. Charging the placement tube with concrete shall not begin until the capped or plugged tip of the placement tube is resting on the bottom of the drilled hole. Once the placement tube has been charged, the pour is initiated by lifting the tip of the placement tube 6 inches above the bottom of the drilled hole. This allows the concrete in the placement tube to force the cap or plug out of the placement tube and discharge. Once the pour has started, it is important to place the concrete at a high rate until the tip of the placement tube is embedded in the concrete. If concrete placement operations slow or stop before the tip of the placement tube is embedded in concrete, there is nothing to prevent the intrusion of drilling slurry into the placement tube. If this happens, the likely result will be a defect at the tip of the pile. Once concrete placement begins, the tip of the concrete placement tube shall not be raised from 6 inches above the bottom of the drilled hole until a minimum of 10 feet of concrete has been placed in the pile. After this level is reached, the tip of the concrete placement tube shall be maintained a minimum of 10 feet below the rising head of concrete. The best way to verify that the tip of the concrete placement tube is being maintained a minimum of 10 feet below the rising head of concrete is for the Contractor to mark intervals of known distance on the placement tube and to measure the distance from the top of the pile to the rising head of concrete with a weighted tape measure. If for some reason concrete placement is interrupted such that the placement tube must be removed from the concrete, the placement tube should be cleaned, capped, and pushed at least 10 feet into the concrete head before restarting concrete placement. Concrete placement continues in this manner until the rising head of concrete reaches the top of the pile. Concrete is then wasted until all traces of particle settlement and drilling slurry contamination are no longer evident. After this has been achieved, the concrete within 5 feet of the top of the pile is vibrated to consolidate the concrete at the top of the pile. Deeper vibration of the pile concrete is not necessary because concrete with high fluidity self-consolidates under the high hydrostatic pressure provided.

The contract specifications also require that the Contractor keep a concrete placement log for the concrete placement operation for each pile. The concrete placement log should contain information on the pile location, tip elevation, dates of excavation and concrete placement, quantity of concrete deposited, length and tip elevation of any temporary casing used, and details of any hole stabilization method that is used. In addition, the log shall include a graph showing the amount of concrete placed versus the depth of the hole filled. This means the Contractor must have a way of accurately measuring the volume of concrete being placed in the pile. For large piles, counting concrete trucks may be sufficient. For small piles, the Contractor may have to use some other means, such as determining the volume of concrete delivered per pump stroke and counting the number of pump strokes. Measuring the depth of the hole filled is usually accomplished using a weighted tape measure to locate the head of concrete within the pile. These readings must be taken at maximum intervals of 5 feet of pile depth.

The purpose of the concrete placement log is to provide the Engineer and the Contractor with a record of the concrete placement operation. It can be used to identify potential problem locations within the pile. Figure 9-18 shows a situation where several hole cave-ins took place. Using the concrete placement log, the Engineer can determine the approximate location of potential problem areas within the pile. Pile testing can then be used to determine whether there is a problem at the suspect area.

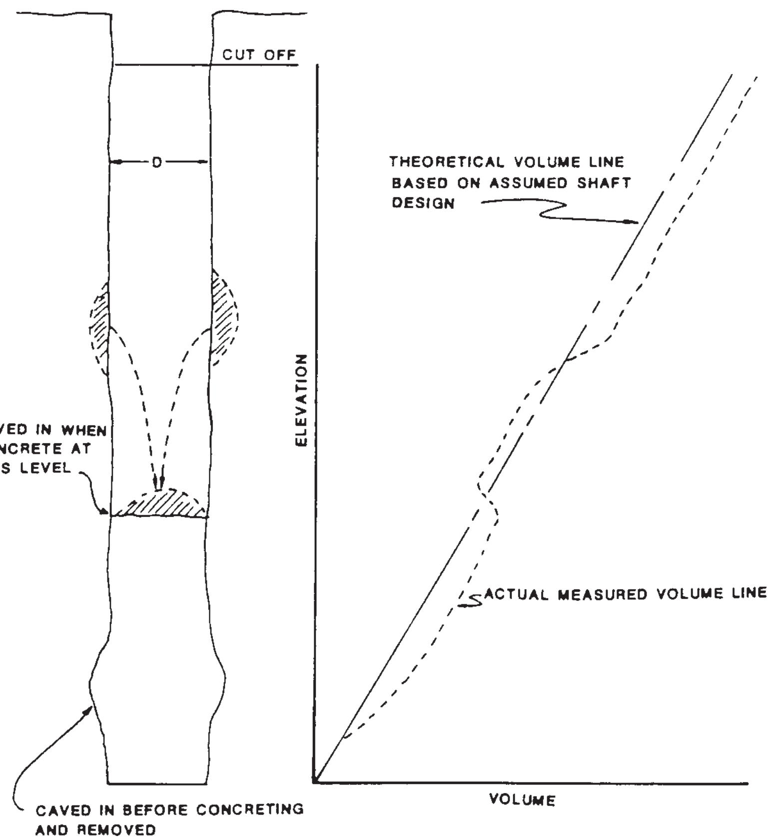


Figure 9-18: Concrete Pile Log Graph

Pile Testing

In order to facilitate pile testing, the contract specifications require the installation of inspection tubes (Figure 9-19). These tubes must be installed inside the spiral or hoop reinforcement of the rebar cage before concrete is placed. Figure 9-20 shows a typical inspection tube layout and spacing pattern within the rebar cage. These tubes must be placed in a straight alignment, securely fastened in place, and be watertight. They permit the insertion of a testing probe that measures the density of the pile concrete. The most commonly used type of test probe is 1.87 inches in diameter and 22.7 inches in length. If the inspection tubes are not placed in a straight alignment or are not securely fastened, the test probe will not fit in the inspection tube. One way of testing the tube would be to try to deflect it by hand. If it can be deflected by hand, it may be deflected by the placement of concrete. It is also recommended that the Contractor install a rigid rod in each inspection tube prior to concrete placement to ensure that the inspection tubes remain straight during and after concrete placement.

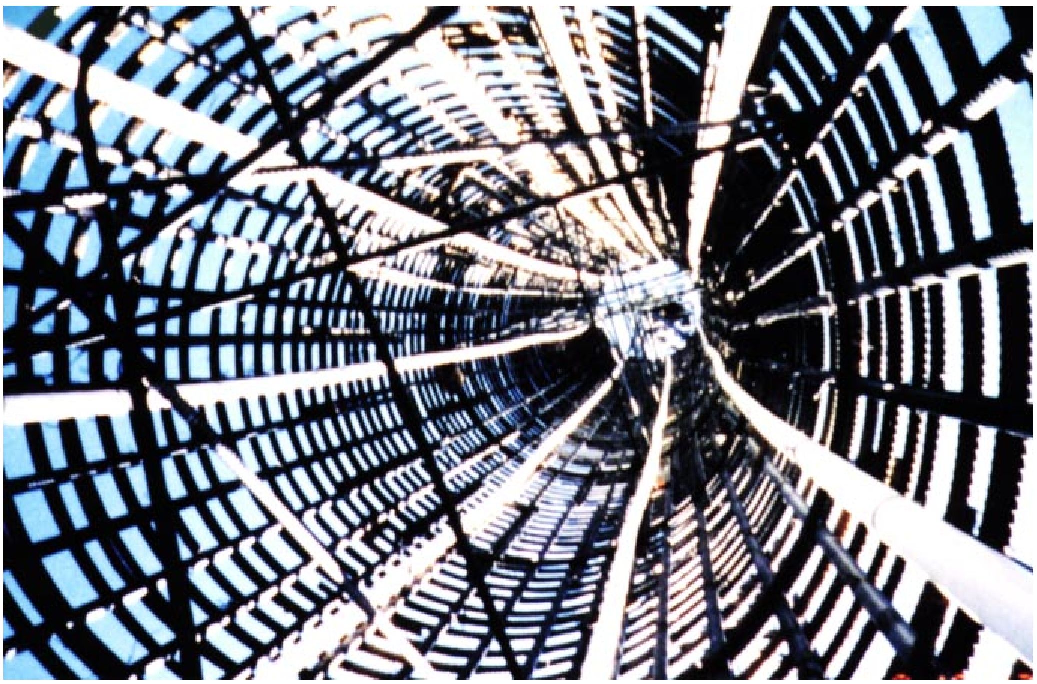


Figure 9-19: Inspection Tubes

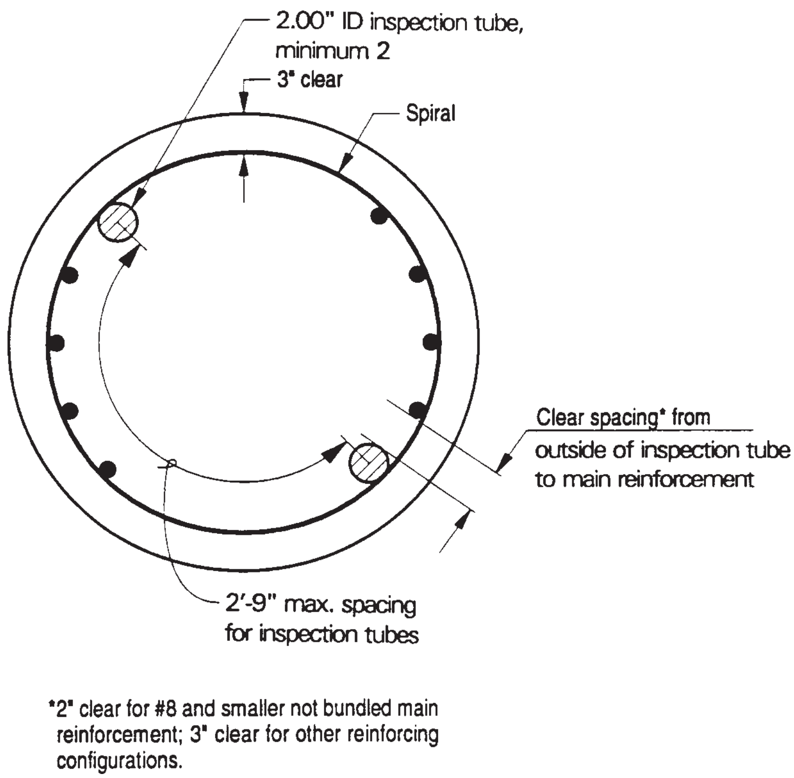


Figure 9-20: Location of Inspection Tubes within the Pile

The Contractor has the responsibility for placement of the inspection tubes. After concrete placement and before testing, the tubes shall be checked for blockages and straightness with a dummy probe which is the same size and shape as the test probe. Tubes that cannot accept the dummy probe shall be replaced with a 2 inch diameter cored hole the full length of the pile.

Determining the soundness of slurry displacement piles is of understandable concern. There are a number of methods that may be used to test the soundness of these piles. One method is the use of external vibration, which measures stress wave propagations in the pile using either internal or external receivers. This requires a variety of expensive electronic gear and skilled operators, as well as the placement of instrumentation on the pile rebar cage prior to concrete placement. Another method uses an acoustical technique, which is commonly referred to as cross-hole sonic logging. This involves lowering sender and receiver probes into the inspection tubes to measure the velocity of sonic waves through the concrete. Defective concrete is registered by the increased amount of time it takes for the sonic wave to be received by the receiver probe, as opposed to the shorter amount of time it takes for the sonic wave to be received across a solid medium (sound concrete). A third method would be to core the pile and recover the physical cores for inspection. This method may be the most conclusive, but is very time consuming. A fourth method uses a radiographic technique called gamma ray scattering (Figure 9-21).

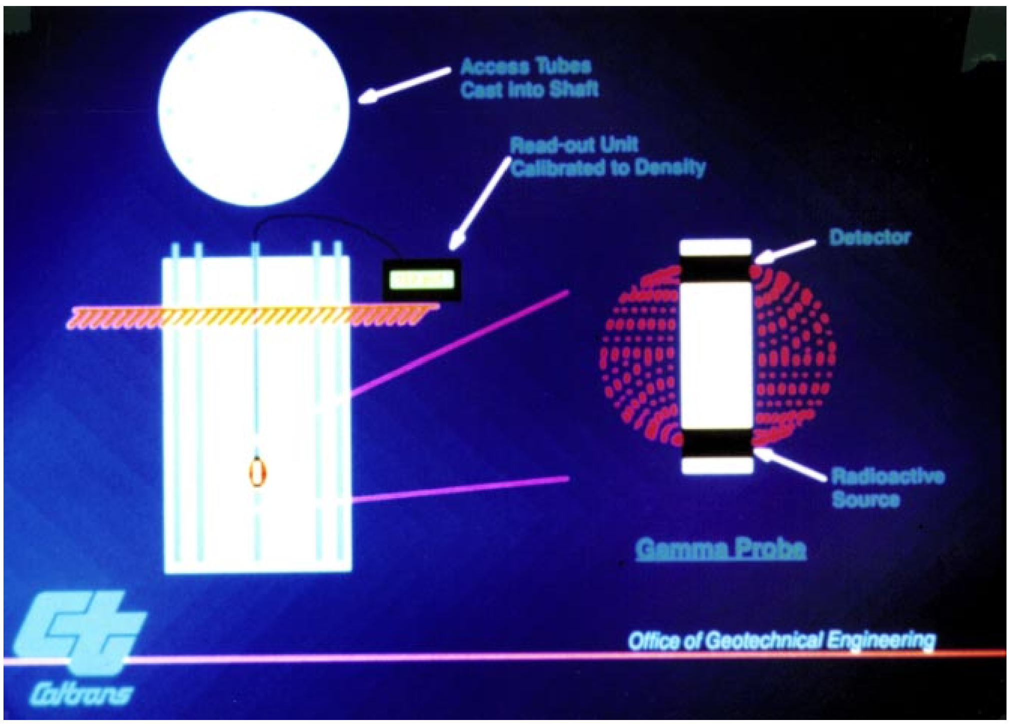


Figure 9-21: Gamma Ray Scattering Test Schematic

As of 1994, the contract specifications state that the gamma ray scattering method of testing piles constructed using the slurry displacement method will be used to determine acceptance of the pile. Other methods may be used in the future as the Office of Structural Foundations develops equipment and expertise.

In gamma ray testing, scatter counts are taken and compared to counts taken on a standard containing the same material being tested. By this means, relative densities can be ascertained. In general, the lower the count, the more dense the material. The nuclear probe used in these tests contains a source which is relatively weak - a plus, considering the precautions that would otherwise have to be taken - and its effective range of sensitivity is limited to a 2 to 3 inch radius of concrete around the tip of the probe. Because of the nature of the data acquired, proper assessment or determination of the existence of defective concrete or voids is subject to interpretation of the results. Typical testing consists of 30 second counts taken at 6 inch increments for the whole length of the pile. This procedure requires about 2-$^1/_2$ hours for a single inspection tube in a 100 foot length pile. Even at this rate, a 48 inch diameter pile containing four inspection tubes would still require 10 hours to check out, assuming there are no access problems in the tubes.

Pile testing is performed by Caltrans personnel from the Office of Structural Foundations of the Engineering Service Center and the results, which include a recommendation of acceptance or rejection, are reported to the Structure Representative in writing. An example of these results can be found in Appendix G.

Occasionally, the Office of Structural Foundations will experience a staffing shortage and may not be able to test the piles. It is important for the Structure Representative to contact the Office of Structural Foundations well in advance of the need for testing so that the Office of Structural Foundations can determine whether they will have the staffing necessary to test the piles. If the Office of Structural Foundations is unable to test the piles, the Structure Representative shall make arrangements for pile testing through the current service contract. The Office of Structural Foundations can provide information on the current service contractor.

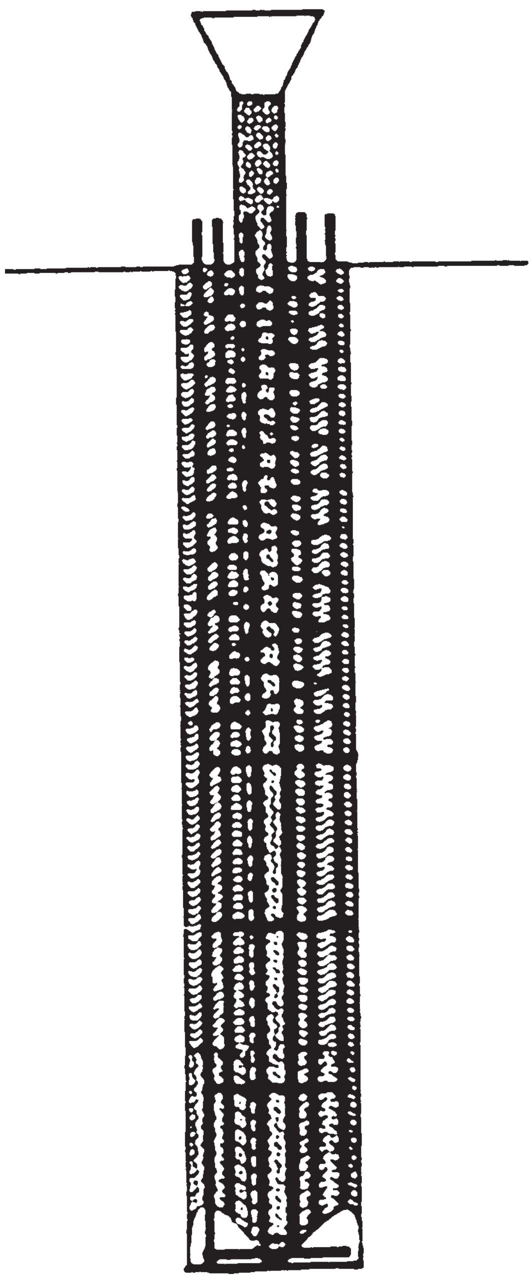
The Structure Representative has the responsibility for accepting or rejecting a pile based on the recommendations of the Office of Structural Foundations. If the pile is accepted, the inspection tubes may be cleaned and grouted, and the pile is complete.

Defective Piles

If the Office of Structural Foundations or the service contractor determines that a pile is defective and the Structure Representative rejects the pile, the Contractor shall be informed in writing that the pile is rejected and given a copy of the test results. The contract specifications also require that the placement of concrete under drilling slurry be suspended until written modifications to the method of pile construction are submitted to and approved by the Engineer. This is to prevent additional failures due to the method of pile construction.

What causes piles constructed by the slurry displacement method to be defective? One of the primary reasons for pile defects is problems caused by settled materials. These are materials that were held in suspension by the drilling slurry that settled out of suspension either before or during the concrete placement operation. These materials can also be the result of improper cleaning of the base of the drilled hole. These materials can be trapped at the bottom of the pile by concrete placement as shown in Figure 9-22(a) or they can be enveloped and lifted by the fluid concrete only to become caught by the rebar cage or against the sides of the drilled hole and not be displaced by the fluid concrete as shown on Figure 9-22(b). These materials can also fall out of suspension and settle onto the head of concrete during concrete placement, become enveloped by the concrete, and attach to the rebar cage or the sides of the drilled hole as previously described. These deposits will register on the pile testing results as areas of lower density than that of sound concrete. Excessive amounts of settled materials can occur in mineral slurries that were not properly cleaned or agitated and carry inordinate amounts of suspended materials. Excessive amounts of settled materials can occur in polymer slurries when not enough time is allowed for the materials to settle out before the final cleaning of the bottom of the drilled hole or if the polymer slurry becomes contaminated from clay-particle encapsulation.

Another reason for pile defects is due to improper drilling slurry handling. If mineral slurries are not properly mixed and are not allowed to properly hydrate, they can form balls or clumps that can become attached to the rebar cage and not be removed by concrete placement as is shown in Figure 9-23. Mineral slurries that remain in the drilled hole for too long can form a filter cake that is too thick for the fluid concrete to scour off the sides of the drilled hole as is shown in Figure 9-24. Mineral and polymer slurries that carry an excessive load of suspended materials can be subject to precipitation if an unexpected chemical reaction takes place. This is possible if the concrete is dropped through the drilling slurry.



(a) (b)

Figure 9-22: Defects from Settled Materials

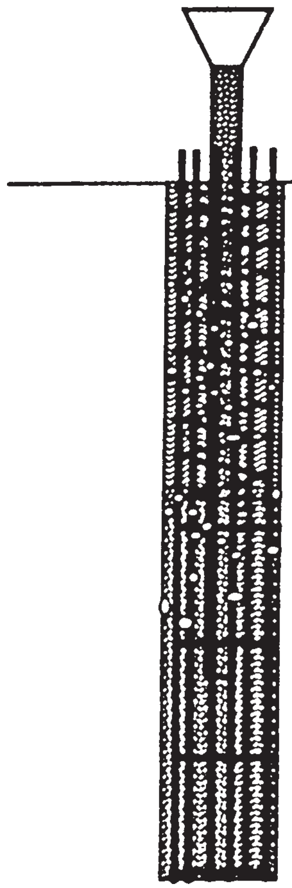


Figure 9-23: Defect from Improperly Mixed Mineral Slurry

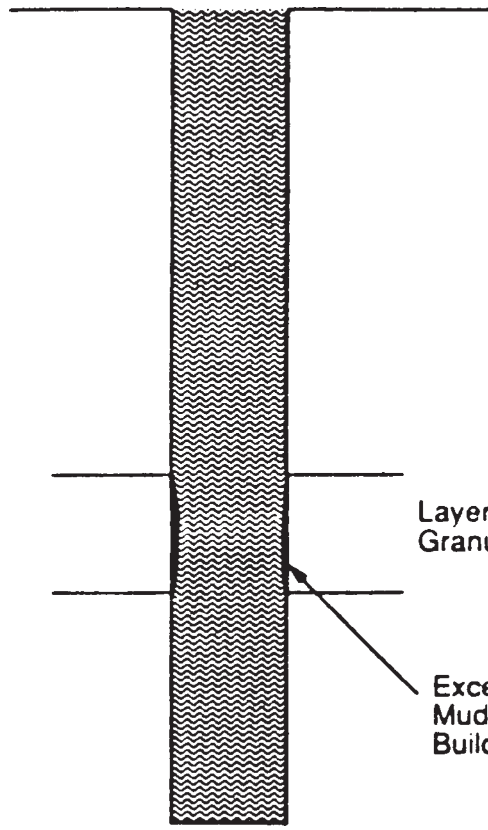


Figure 9-24: Defect from Excess Filter Cake Buildup

A third reason for pile defects is concrete mix design and placement problems. Whenever the seal between the head of concrete and the drilling slurry is lost, a defect is very likely to result. This is because entrapment of drilling slurry within the concrete is almost inevitable under this circumstance (Figure 9-25). If the concrete placement tube loses its seal and allows concrete from the placement tube to drop through the drilling slurry onto the head of concrete, the drilling slurry and any settled material on the head of concrete could be trapped between the concrete layers, causing a pile defect. If the concrete head begins to set, the concrete can "fold" over as it is rising through the rebar cage and entrap drilling slurry and any settled materials as previously described. Another type of pile defect can result due to concrete mix design problems. The Engineer should not permit the use of excess water in the concrete mix design or allow additional water to be mixed with the concrete at the jobsite to provide the necessary fluidity. This may result in severe bleedwater from the concrete after placement, which could indicate segregation and subsidence of the pile concrete. This may cause the entire pile to be defective. If excess free water in the concrete is present when polymer slurries are used, the excess free water will attract the polymer chains from the drilling slurry into the concrete and produce a material contaminant known as oatmeal at the concrete-slurry interface. This material can potentially be caught on the rebar cage and cause pile defects.

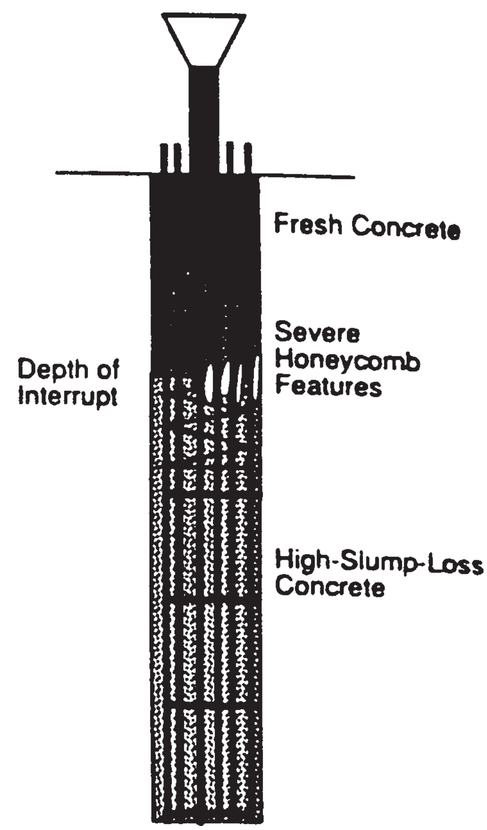


Figure 9-25: Defect from Concrete Placement Problems

These types of problems can be avoided if the Contractor and the Engineer closely follow the parameters specified in the contract specifications. These specifications help to ensure the proper mixing and properties of drilling slurries, the proper qualities of the concrete mix design, and the proper methods of concrete placement.

Once a pile has been determined to be defective, the Contractor has several options. The defect can be accessed and repaired, the pile can be supplemented, the pile can be replaced, or the Contractor may propose a solution that allows the pile to remain in place. For whatever solution the Contractor proposes, additional investigation will be necessary to determine the nature and extent of the defect. Other methods of pile testing, such as cross-hole sonic logging or coring, may be used to perform this investigation. An investigation of the ground formation will also be necessary since potential pile rebar corrosion will be a major concern. These investigations are to be performed by the Contractor at the Contractor's expense. With the additional information, the Contractor can propose a solution that may not require access to the defect or replacement of the pile. Methods of repair that would not require the defect to be exposed include the placement of supplemental piles and the use of pressure grouting. If a supplemental pile is proposed, the Engineer should keep in mind that corrosion of the existing pile rebar that may be exposed to the soil may be a concern. The Contractor must investigate the corrosive nature of the soil at the site of the defect before the existing pile can be assumed to have any capacity in combination with a supplemental pile. Pressure grouting is usually most effective as a means of improving the quality of the concrete at the tip of the pile. Any proposal made by the Contractor should be investigated by the Office of Structure Design and the Office of Structural Foundations to ensure that the pile will have sufficient structural and geotechnical capacity before approval is given.

Safety

Safety concerns to be considered during the construction of CIDH piles by the slurry displacement method are similar to those to be considered when CIDH piles are constructed by ordinary means. For specific information, refer to Chapter 6 of this manual. However, there is one additional item that requires further attention, which is the drilling slurry itself.

Some of the components of drilling slurries, especially chemical additives, are considered to be hazardous materials. It is advisable to avoid skin contact and to avoid breathing in vapors. The Construction Safety Orders require the Contractor to provide Material Safety Data Sheets (MSDS) for *all* drilling slurries and chemical additives. The Engineer should obtain these MSDS sheets as part of the submittal for the pile placement plan. During the tailgate safety meeting prior to CIDH pile construction, be sure to discuss the contents of the MSDS and discuss how the safety precautions will be adhered to by Caltrans employees, the Contractor's employees, and any manufacturer's representatives that may be present.

During construction, do not permit the use of drilling slurries or chemical additives for which a MSDS has not been submitted.

Specifications

Because of the nature of slurry displacement construction, visual inspection of the drilled shaft is not possible for much of the time. Most of the drilling and concrete placement is done "in the blind". As a result, the contract specifications for this work, which were revised in 1994, are quite stringent in an attempt to minimize the risks and to ensure that the pile has structural and geotechnical integrity. Some of the more critical requirements of the contract specifications are discussed in the following sections.

Minimum Pile Diameter Requirements

Only piles 24 inches in diameter or greater may be constructed by the slurry displacement method. This is because a pile with a lesser diameter may not contain enough room for the rebar cage, inspection tubes, and the large concrete delivery tubes. If a contract specifies the use of piles with a diameter of less than 24 inches, the Contractor may propose to increase the diameter of the pile to at least 24 inches by the provisions described in Section 49-4.03 of the Standard Specifications if use of the slurry displacement method of construction is desired. However, the diameter of the rebar cage would have to be increased from the original size in order to accommodate the items mentioned above.

Pile Placing Plan Requirements

Before any pile construction work using the slurry displacement method can begin, the Contractor shall submit a detailed placing plan to the Engineer for approval. The placing plan is necessary to show that the Contractor has thought out what needs to be done during the construction process, has a plan for addressing *all* aspects of the work, and can show that the pile can be constructed in a timely manner. Because the contract specifications state that the Contractor shall place the concrete for a single pile within a two hour period, the Contractor must be able to show that the equipment, including concrete pumps and delivery tubes, will be adequate to meet this requirement. The Contractor must also show that the delivery rate from the concrete supplier will be adequate to meet this requirement. The intent of this specification is to limit the amount of time in which suspended materials can settle out of the drilling slurry during concrete placement and to make sure the concrete retains high fluidity throughout the length of the pour. The amount of detail required for the Contractor's submittal will vary based on the size and depth of the drilled hole.

Concrete Compressive Strength and Consistency Requirements

Before any pile construction work using the slurry displacement method can begin, the Contractor shall demonstrate the concrete mix design can meet the required compressive strength requirements and consistency requirements. This is accomplished by producing a concrete test batch. The concrete test batch must demonstrate the proposed concrete mix design achieves the specified nominal penetration at the time of placement and a penetration of at least 2 inches after a period of four hours has passed from the time of placement. The intent of this specification is to make sure the first load of concrete placed in the drilled hole will remain sufficiently fluid as it rises to the top of the pile. The concrete must also have a high fluidity in order to flow through the rebar cage, compact and consolidate under its own weight without the use of vibration, and to deliver high lateral stresses on the sides of the drilled hole in order to keep the drilled hole from collapsing as the drilling slurry is displaced and the filter cake (in the case of mineral slurries) is scoured from the sides of the drilled hole by the rising column of concrete. The concrete test batch and compressive strength requirement give the Engineer and the Contractor the opportunity to observe how the concrete mix will behave before it is used.

Slurry Testing and Cleaning Requirements

During pile construction work, the contract specifications require the Contractor to sample and test the drilling slurry in order to control its physical properties. The contract specifications also require that each type of drilling slurry be sampled and tested at different intervals and locations.

For mineral slurries, samples shall be taken from the mixing tank for testing prior to the mineral slurry's introduction into the drilled hole. Once the mineral slurry has been introduced into the drilled hole, the contract specifications require the mineral slurry to undergo either recirculation or continuous agitation in the drilled hole. The Contractor must address which method of agitation will be used in the pile placement plan.

If the recirculation method is used, the contract specifications require the mineral slurry to be cleaned as it is recirculated. This is done using a slurry plant, which stores, recirculates, and cleans the mineral slurry. Samples for testing shall be taken from the slurry plant storage tank and the bottom of the drilled hole. As the mineral slurry is recirculated and cleaned, samples shall be taken every two hours for testing until the test values for the samples taken at the two testing locations are consistent. Once the test samples have consistent test values, the sampling and testing frequency may be reduced to twice per workshift. As the recirculation and cleaning process continues, the properties of the mineral slurry will eventually conform to the specification parameters. Once the test samples have properties within the specification parameters, the bottom of the drilled hole can be cleaned.

If the continuous agitation in the drilled hole method is used, the contract specifications do not require the mineral slurry to be physically cleaned. Samples for testing shall be taken at the midheight and at the bottom of the drilled hole. As the mineral slurry is continuously agitated, samples shall be taken every two hours for testing. If the samples at the two locations do not have consistent test values, *the mineral slurry shall be recirculated*. This means that the continuous agitation in the drilled hole method is failing to keep the suspended particles in the mineral slurry from settling. This is also an indication that the mineral slurry is not clean enough to meet the specification parameters. Therefore, the Contractor is required to abandon this method and use the recirculation method. However, if the test samples do have consistent test properties within the specification parameters, the bottom of the drilled hole can be cleaned.

Once the bottom of the drilled hole has been initially cleaned, recirculation or continuous agitation in the drilled hole may be required to maintain the specified properties of the mineral slurry. Usually the initial cleaning will stir up the settled materials at the bottom of the drilled hole, thus requiring the mineral slurry to be recleaned so it meets the requirements of the contract specifications. Several iterations may be required before both the mineral slurry and the bottom of the drilled hole are clean. To verify the cleanliness of the mineral slurry, the contract specifications require additional samples to be taken for testing. Samples shall be taken at the midheight and at the bottom of the drilled hole. Once the test samples show the mineral slurry's properties to be within the specification parameters and there is no settled material on the bottom of the drilled hole, the last cleaning of the bottom of the drilled hole can be considered to be the final cleaning. At this point, the rebar cage can be placed. The contract specifications require that samples for testing be taken just prior to concrete placement to verify the properties of the mineral slurry. Samples shall be taken at the midheight and at the bottom of the drilled hole. If the test samples have consistent test properties within the specification parameters, concrete may be placed.

Otherwise, additional cleaning of the mineral slurry and removal of settled materials from the bottom of the drilled hole may be required.

The reason for testing mineral slurries at different levels is to make sure the mineral slurries are well mixed and have consistent physical properties throughout the length of the drilled hole. The mineral slurry's physical properties should be the same at both locations. This indicates that the mineral slurry is completely mixed and that any sand or particles contained are in suspension.

For polymer slurries, sampling for testing shall be conducted as necessary to control the physical properties of the polymer slurry. Samples shall be taken at the midheight and at the bottom of the drilled hole. Samples for testing shall be taken as necessary to verify the properties of the polymer slurry during the drilling operation. Once the drilling operation has been completed, samples for testing shall be taken. When the polymer slurry's physical properties are consistent at the two sampling locations and meet the requirements of the contract specifications, the bottom of the drilled hole can be cleaned.

Polymer slurries are cleaned by allowing for an unagitated settlement period, usually of about 30 minutes in length. Because polymer slurries in general will not suspend sands, the sands will settle to the bottom of the drilled hole during the settlement period.

Once the bottom of the drilled hole has been initially cleaned, further settlement periods may be required. Usually, the initial cleaning will stir up the settled materials at the bottom of the drilled hole, thus requiring the polymer slurry to be recleaned so it meets the requirements of the contract specifications. Several iterations may be required before both the polymer slurry and the bottom of the drilled hole are clean. To verify the cleanliness of the polymer slurry, the contract specifications require additional samples to be taken for testing. Samples shall be taken at the midheight and at the bottom of the drilled hole. Once the test samples show the polymer slurry's properties to be within the specification parameters and there is no settled material on the bottom of the drilled hole, the last cleaning of the bottom of the drilled hole can be considered to be the final cleaning. At this point, the rebar cage can be placed. The contract specifications require that samples for testing be taken just prior to concrete placement to verify the properties of the polymer slurry. Samples shall be taken at the midheight and at the bottom of the drilled hole. If the test samples have consistent test properties within the specification parameters, concrete may be placed. Otherwise, additional settlement periods and removal of settled materials from the bottom of the drilled hole may be required.

The reason for testing polymer slurries at different levels is to make sure the polymer slurries are well mixed and have consistent physical properties throughout the length of the drilled hole.

The intent of these specifications is to ensure that the drilling slurry is properly mixed in order to provide stability to the drilled hole and to control the amount of suspended materials in the drilling slurry which may settle during placement of the rebar cage and concrete.

Pile Testing Access Requirements

During pile construction work, the contract specifications require the installation of inspection tubes at specific intervals around the perimeter of the bar reinforcement cage. This is necessary to provide access for structural integrity testing.

Pile Concrete Placement Requirements

During pile construction work, the contract specifications require that concrete shall be placed through rigid tremie tubes with a minimum diameter of 10 inches or through rigid pump tubes. The tubes are required to be capped or plugged with watertight plugs that will disengage once the tubes are charged with concrete. The tip of the concrete placement tube is required to be located a minimum of 10 feet below the rising head of concrete.

The intent of these specifications is to prevent the concrete placement tubes from allowing the concrete and drilling slurry to intermingle during concrete placement.